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VOSKHOD AND VOSKHOD 2

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RESULTS OF SOME MEDICAL INVESTIGATIONS ON THE SPACECRAFT
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ABSTRACT

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The report presents the results of some medical (chiefly physiological) investigations carried out during flights on the spacecraft Voskhod and Voskhod 2 which, according to the authors, may be of interest in connection with the outlook for space travel, including manned flight to the moon.

author

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From the medical and biological standpoint, flight to the moon is a realistic goal. A solution of the problems involved requires:

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- (1) biological interpretation of the available physical data on outer space;
- (2) experimental biological reconnaissance of the proposed space routes in order to detect potential dangers to manned flight;
- (3) solution of numerous medical problems in selecting and training the crew, developing life-support and rescue systems and methods of preserving the fitness of the cosmonauts.

The medical research carried out in 1961-1963 in connection with the Vostok program demonstrated the possibility of 5-day orbital flights. V. Bykovskiy readily tolerated the conditions existing during this flight. He remained completely fit and able to carry out his flight assignment in toto.

The advances in space and rocket technology in the USSR led to the building of multiplace spacecraft of the Voskhod type, the flights on which in 1964-1965 introduced important new elements, crews comprising several different specialists (pilot-cosmonaut, physician, physicist), inclusion of a wider range of

*Numbers given in the margin indicate the pagination in the original foreign text.

medical and physicotchnical investigations, performance of a variety of operations, and emergence into "free outer space."

The results of the investigations are of great independent interest ^{/3} and they will undoubtedly be widely used for designing programs and safeguarding future flights, including those planned for the moon.

As for the human factor, the authors believe that special attention will have to be devoted to such problems as the effect of prolonged weightlessness, radiation hazards, emotional stress, determination of human capabilities in controlling the spacecraft, observation and performance of operations involved in assembling space objects.

The flight programs entailed the execution of a great number of research tasks, particularly those pertaining to medicine and biology. Since the data amassed have not yet been completely processed, the results presented below are tentative.

1. Brief Description of Flight Conditions

The data characterizing the main parameters of the orbits of Voskhod and Voskhod 2 and the duration of the flights are summarized in the table.

Unlike the preceding Vostok flights, the apogee of which was about 230-330 km, the Voskhod flights took place in more distant orbits (with an apogee of ^{/4} 409-490 km) closer to the radiation belts. This seems to be the reason that the total dose received by each cosmonaut during the day-long flight of Voskhod 2 was about 70 mrad, or almost double that received by the cosmonauts on the Voskhod (about 30 mrad). No appreciable difference was noted between the value of the dose absorbed by P. Belyayev, who remained in the spacecraft, and that absorbed by A. Leonov, who left it. Based on the readings of the dosimeters and results of the investigation of the biological objects and tests, it is ^{/5} unlikely that the cosmonauts were adversely affected by ionizing radiation.

The hygienic parameters inside the pressurized Voskhod cabins did not exceed either the permissible or the theoretical values. Thus, they by themselves could not have produced any abnormalities in the physiological condition of the cosmonauts. The desired parameters of the microclimate of the cabin were achieved and stabilized by turning on the regeneration and air conditioning system four hours before launching.

To carry out the operation of emerging into outer space, the crew of Voskhod 2 wore suits with an autonomous oxygen supply system. Before stepping out of the cabin, the cosmonaut shifted to breathing pure oxygen.

Since increased expenditures of energy were anticipated, the calorie value of the ration for the crew of Voskhod 2 was raised to 3250 kcal from the 2800 allotted to the crew of Voskhod. The main food constituents were: protein - 170 gr, fat - about 150 gr, carbohydrate - about 450 gr; vitamins: C - 200 mg,

TABLE 1

Serial number	Spacecraft	Crew	Date of launching	Number of orbits	Duration of flight (hours)	Initial orbit parameters				Remarks
						apogee, km	perigee, km	slope, degrees	time, min	
1	Voskhod	V. Komarov B. Yegorov K. Feoktistov	12 October 1964	16	24	409	178	65	90.1	
2	Voskhod 2	P. Belyayev A. Leonov	18 March 1965	17	25	495	173	65	90.9	Emergence from the spacecraft

P - 100 mg, PP - 30 mg, B₁, B₂, B₆, folic acid - 4 mg each, and some others.

The supply of drinking water was increased proportionately (to 2 liters per man per day). The menu was varied and took into account the individual tastes of the cosmonauts. Provision was made for 4 or 5 meals a day.

The work and rest routines on both spacecraft were determined by the flight assignment. The men took turns in resting. However, owing to the unusual situation and to the enthusiasm with which the cosmonauts applied themselves to their tasks, the time set aside for rest or sleep was not fully used. 16

The flight assignment included a variety of tasks: control of the ship, solution of navigational problems, radio communication, scientific investigations, "emergence" from the cabin during the last flight, and carrying out the elements of assembly work.

Each of the described flights was planned to last one day.

2. Methods of Medical Investigations during Flight

Two groups of methods were used: (1) those to check on the condition of the cosmonauts; (2) those designed to study the nature of the reactions and efficiency of the cosmonauts.

The inclusion of Dr. B. Yegorov in the Voskhod crew made it possible to considerably broaden the scope of medical investigations by using, in addition to biotelemetry systems, other methods not involving the transmission of information via the radiotelemetry system. The following parameters were 17 recorded: electrocardiogram, seismocardiogram, pneumogram, electroencephalogram, electrooculogram, and some others. In addition, blood samples were taken, pulmonary ventilation was determined, vestibular function was tested, etc.

A feature of the medical supervision on Voskhod 2 was that it not only ensured that the required information would be obtained by ground observation points, but enabled the commander of the craft to check on the condition of the other cosmonaut after he emerged into outer space. Meanwhile, the electrocardiogram, pneumogram, and various hygienic parameters of the atmosphere in the suit were also recorded. The method of arranging and fastening the sensors guaranteed the reliable production of information with due regard for the physical exertions of the cosmonauts.

Considerable attention was paid to the question of human efficiency and functional capabilities. Specifically, studies were made of the resolving power and some functional characteristics of the visual analyzer, several dynamic characteristics of the human operator included in a model of a control system, persistence of habits, etc.

The condition of the cosmonauts during flight was evaluated from the biotelemetric data, analysis of radio conversations, television observations of the external appearance and nature of the activity, and the personal reports of the men.

The active portion of the flight was well tolerated by all five cosmonauts. No unpredicted physiological reactions occurred. On the contrary, it was our impression that the indices of the cardiovascular and respiratory systems changed less in the crews of Voskhod and Voskhod 2 than they did in the crews of the Vostoks. For example, whereas the pulse rate of V. Bykovskiy was 137 per min and that of V. Tereshkova 151, the rates for V. Komarov, K. Feoktistov, and B. Yegorov were 98, 102 and 109, respectively. The transition from acceleration to weightlessness was smooth and "imperceptible," as the cosmonauts characterized it. Under the conditions of weightlessness, the functional indices of the Voskhod cosmonauts, consistent with the already known data, returned to normal. The indices recorded during the flight of Voskhod 2 were somewhat unusual. After the craft went into orbit, the cardiac rate of P. Belyayev and A. Leonov actually increased somewhat and there was a fairly pronounced sinus tachycardia, apparently caused by the performance of operations preparatory to the second cosmonaut leaving the craft. At the same time the respiratory rate also increased (fig. 1). These reactions were more or less similar to those noted in training exercises simulating emergence onto the Earth. /8

Investigation of the oculograms of P. Belyayev and A. Leonov showed a high rate of eyeball movements during the first to fourth orbits, another indication of the intensified activity of the cosmonauts during this stage of the flight (fig. 1). /9

At the moment that he stepped out of the cabin and while he was in outer space, Leonov's pulse and respiratory rates increased. This was certainly attributable to natural emotional tension. But these indices quickly returned to normal after he re-entered the craft. For example, just before leaving the air lock, Leonov's pulse rate was 100-120 beats per min, or about the same as when he was going through similar training exercises on Earth. When he left the lock, the rate rose to 150-160; on entering the lock, when he had to cope with

some problem, it rose to 168, but after entering the lock, it dropped fairly quickly to 100-120 (fig. 2).

We shall discuss in more detail the cosmonaut's behavior outside the spacecraft because it is pertinent to the possibility of carrying out various operations on future flights, e.g., in assembling space objects. It is interesting to note that in weightlessness even a comparatively slight exertion involves rotating the body in several planes with a fairly high angular velocity. This was confirmed by moving pictures taken during the emergence of the cosmonaut. Both Leonov's report and the biotelemetric data gave no indications of any autonomic disturbances arising as a result of vestibular and optokinetic stimulation. Preliminary biomechanical analysis of Leonov's movements outside the craft (as in the case of ground investigations on a special stand) reveals /10 quite satisfactory coordination and ability to carry out planned movements and actions with the help of a piece of rope. He managed to get the movie camera ready and dismount it before returning to the craft. All the operations were performed by hand without any difficulty.

The problem of spatial orientation in weightlessness deserves special attention. In the cabin, "up-down" was determined by its interior, and even while the craft was rotating relative to the plane of the orbit, the cosmonauts felt no sensation of turning over. The tentativeness of the ideas of "up-down" and the practical necessity for precise orientation in space outside the craft required that a system of coordinates be selected that would take into account its long axis and the position of the sun. Orientation was also eased by the fact that on "top" of the air lock chamber was a camera. But it became difficult on entering the lock. Yet Leonov did not experience any disagreeable sensations. After leaving the spacecraft, he used the system of coordinates according to a diagram. However, if the vehicle did not come into his field of view, spatial orientation was impaired and it was difficult to quickly determine the probable location of the craft. On the whole, we have the impression that Leonov was in command of the situation and that, despite its new and unexpected aspects, he was under no undue nervous or emotional stress. All this testifies to the importance of selecting visual orientation points and developing the requisite skills beforehand. This circumstance, it seems to us, confirms the existing conceptions of the physiological mechanisms of spatial analysis /11 with interaction of the sensory organs (analyzers), particularly the visual and kinesthetic. Visual information about the location of objects in space seems to suppress unusual vestibular signals, "sets in order" the information of the sense organs, and enables man to determine accurately the position of his body in space.

The foregoing is very encouraging with respect to man's being able to perform operations outside a spacecraft. But it should not lead to overconfidence, for what has been accomplished is just the first step, and the problem is far from being solved.

The problem of weightlessness remains, as before, an urgent one from the theoretical and practical standpoints. The observations made on the Voskhod and Voskhod 2 are of great interest in this respect. Some cosmonauts (Yegorov and Feoktistov) experienced disagreeable vestibular-autonomic reactions, mild nausea (Yegorov), illusions of spatial position (with head or face down) with

open and with closed eyes. These symptoms appeared 1-1/2 - 2 hours after the launching and, although they did not interfere with the planned work, they persisted virtually throughout the flight. It is worth mentioning that they clearly had nothing to do with stabilization or rotation of the craft around its axis, for they occurred both when the craft was completely stabilized and when it was rotating (about one turn in 20-40 seconds). The cosmonauts on Voskhod and Voskhod 2 noted that moderate physical exertion produced a noticeable tendency to perspire and at times increased fatigability. All this implies changes in regulation of autonomic functions in weightlessness and dictates the need of further research, especially in connection with extended flights.

It will be noted that there were no new changes in the indices of the physiological functions of the crews of Voskhod and Voskhod 2. As mentioned above, the biotelemetric data were, in general, similar to those recorded during previous flights. Yegorov detected in his colleagues a not unexpected lowering of arterial pressure. The lowering of maximum arterial pressure and elevation of minimum pressure caused their pulse pressure to drop slightly. For example, in Komarov, the maximum arterial pressure dropped to 95 mm Hg as compared with 115 before the launching, whereas the minimum pressure rose from 65 to 80 mm Hg. The vagotonic reaction predominated slightly. For example, Yegorov's pulse during the flight reached 46 beats per minute. But even on Earth his pulse sometimes decreased to 52 while sleeping. One of the authors (Gazenko) presented a physiological interpretation of these phenomena in a paper read at the Third Symposium on Bioastronautics held in Texas in November 1964. /12

Analysis of blood samples of Feoktistov and Yegorov obtained during the second and twelfth orbits of Voskhod failed to reveal any changes in carbohydrate or salt metabolism. It is also worth noting the slight increase in blood urea to 41-51 mg percent, whereas the control samples never exceeded 40 mg percent. This may indicate some intensification of protein decomposition during flight. Also, Yegorov developed a leukocytosis. /13

Pulmonary ventilation increased appreciably during flight. For example, it increased two- to three-fold in Belyayev and Leonov. Changes in oxygen consumption were ambiguous and no definite conclusions can be drawn owing to the meagerness of the available data.

Functional cardiovascular tests (passive orthostatic test, test with graduated physical exercise) 24 hours after flight showed some peculiar reactions. For example, the reaction to exercise was somewhat more pronounced and the restoration period lasted longer than before flight. The stroke and minute volumes also decreased (by 26-47 percent in Feoktistov and Yegorov) and pulse pressure dropped (by 10-24 mm Hg). Arterial pressure dropped in Yegorov after the functional test.

Biochemical analysis of the blood after flight showed an increase in cholesterol. For example, the evening after the flight of Voskhod, the cholesterol content was 260-290 mg percent instead of the cosmonauts' usual 120-180 mg percent. The following morning it was 220-260 mg percent. It did not completely return to the original level until 2 weeks later.

These data probably signify some strain on lipid metabolism arising during flight and the possibility of a fairly long residual effect.

The crew of Voskhod exhibited considerable individual variations in ^{/14} blood sugar after the flight. For example, Yegorov had a low sugar concentration, whereas it was rather high in Komarov. Investigation of the excretion of 17, 21-oxy-20 ketocorticosteroids and ratio in urine revealed no significant abnormalities. However, these were the results of a 24-hour flight and a more pronounced reaction should be expected after longer flights.

The day after the flight Belyayev's energy expenditure exceeded the original values by 29 percent, while that of Leonov, by only 13 percent.

Two days after the flight, kidney function was tested in Komarov and Yegorov by the water load method. Water was eliminated more slowly than before or 2 weeks after the flight. There were no indications of impaired glomerular filtration or concentration capacity of the kidneys. It is worth noting that the cosmonauts were not thirsty during flight, although their water loss was fairly high, but they felt very thirsty as soon as they landed. These phenomena were probably due to nervous and emotional strain and hormonal changes during flight.

The changes in energy expenditure and water metabolism provide additional material for elucidating the familiar phenomenon of weight loss by the cosmonauts after flight. After the flights of Voskhod and Voskhod 2, Komarov ^{/15} lost 1.9 kg, Feoktistov lost 2.9 kg, Yegorov lost 3 kg, Belyayev lost 1 kg, and Leonov lost 0.9 kg.

A comparison of the physiological data recorded during flights of different duration (Vostoks) with the materials of the flights of the 3 cosmonauts (Voskhod) and 2 cosmonauts (Voskhod 2) helps to evaluate emotional stress in the picture of the physiological reactions, individual mental and physiological characteristics of the cosmonauts, and the factor of flight duration. For example, flights with more than one person are definitely superior, from the medical and psychological points of view, to solo flights. This is evident both from the nature and intensity of the physiological reactions during virtually all phases of the flight and even in the prelaunching period (table 2).

Table 2 shows the changes in pulse rate in Bykovskiy and Tereshkova ^{/16} and in the Voskhod cosmonauts before the launching and during the active part of the flight. The favorable effect of the "feeling of fellowship" is readily apparent from the figures.

Another significant influence is the work routine. At the least, under certain conditions, the work dominant is a major normalizing factor. For example, despite the unusual flight conditions and "emergence" into outer space (such as Leonov experienced when he went through the air lock and found himself outside the spacecraft), his work routine clearly "suppressed" the disagreeable sensations that were possible in this situation and overcame the spatial disorientation resulting from weightlessness.

TABLE 2

Spacecraft	Cosmonauts	Original values per min	5 and 1 min before the launching and during the active part of the flight, in percent of origi- nal level		
			5 min	1 min	active part
Vostok 5	V. Bykovskiy	64	207	226	214
Vostok 6	V. Tereshkova	78	162	178	194
Voskhod	V. Komarov	72	152	124	136
Voskhod	K. Feoktistov	76	118	126	134
Voskhod	B. Yegorov	63	136	149	175

New information brings with it new problems. Among them, human efficiency during space flight is undoubtedly of special interest. The cosmonauts had no difficulty in performing the manipulations called for in the program. Coordination of movements was fairly simple. However, analysis of the time required to perform certain operations (handling of equipment, carrying out of plethysmometry, etc.) showed that at the beginning of a flight we must expect that the cosmonauts will take a little more time as compared with the standards on Earth or with the time they may require to perform them during later stages of the flight. For example, during the first orbit Komarov spent about twice as much time in carrying out certain manipulations involved in orienting the vehicle as he did during subsequent orbits or on Earth. Yegorov observed the same thing when taking physiological measurements. This phenomenon may be due to the effect of "external inhibition" resulting from the novelty of the situation and from a restructuring of habits as applied to weightless conditions. The phenomenon generally leveled out and was compensated during the later phases of the flight. /17

Investigation of the resolving power of the visual analyzer (with due regard for the nonstandard lighting conditions) failed to turn up any significant changes. Functional visual efficiency may have at times diminished but not markedly so.

Investigation of the characteristics of the operator in a model control system was highly interesting. Use was made of graduated, random, and sinusoidal signals with certain frequency characteristics. The operator (cosmonaut) was able to exercise control by direct or delayed feedback in the system. It was found that the standard deviation of the operator during flight conditions increased over the values obtained during training in a mock-up of the spacecraft. It was more noticeable at the greater signal frequencies. Yegorov also concluded that the cosmonauts' efficiency may, in general, be less during flight than when performing similar operations on Earth (as far as the time required to perform the operations and the quality of the work are concerned). At the same time it was shown that there was no impairment of well-mastered elementary skills required for the programmed operations. /18

Thus, the available data indicate that the cosmonauts retain a level of efficiency sufficient to enable them to execute in full a varied flight program. The results of the physiological observations made in the course of the 24-hour flights as well as the subsequent clinical and physiological examinations revealed no evidence that the principal functional systems were disrupted. Nevertheless, we must not ignore the possibility that vestibular-autonomic disorders, fatigue, or functional changes in blood circulation or metabolism may arise during a flight. Suitable preventive measures and training programs must be devised.

We have every reason to believe that sound methods of selecting and training personnel and the vast capabilities of man to adapt to new environmental conditions combined with certain protective measures will lead to further progress in accomplishing longer, more difficult flights.

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